

Observation of Events at Very High Q^2 in ep Collisions at HERA

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On behalf of the
H1 Collaboration

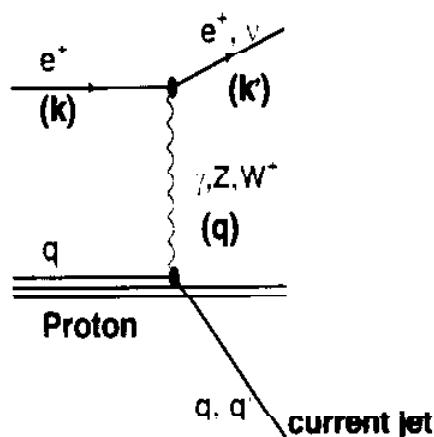
April 1997



Deep-inelastic Scattering at HERA

$E_e = 27.5 \text{ GeV}$

$E_p = 820 \text{ GeV}$



$$\sqrt{s} \approx 300 \text{ GeV}$$

$$Q^2 = -q^2$$

$$x = \frac{Q^2}{2P \cdot q}$$

$$y = \frac{P \cdot q}{P \cdot k}$$

Mass in electron-parton system:

$$M = \sqrt{xs}$$

Angle of scattered electron

in $e-q$ center of mass:

$$y = \frac{1}{2} (1 + \cos \Theta_e^*)$$

Resolution of probe:

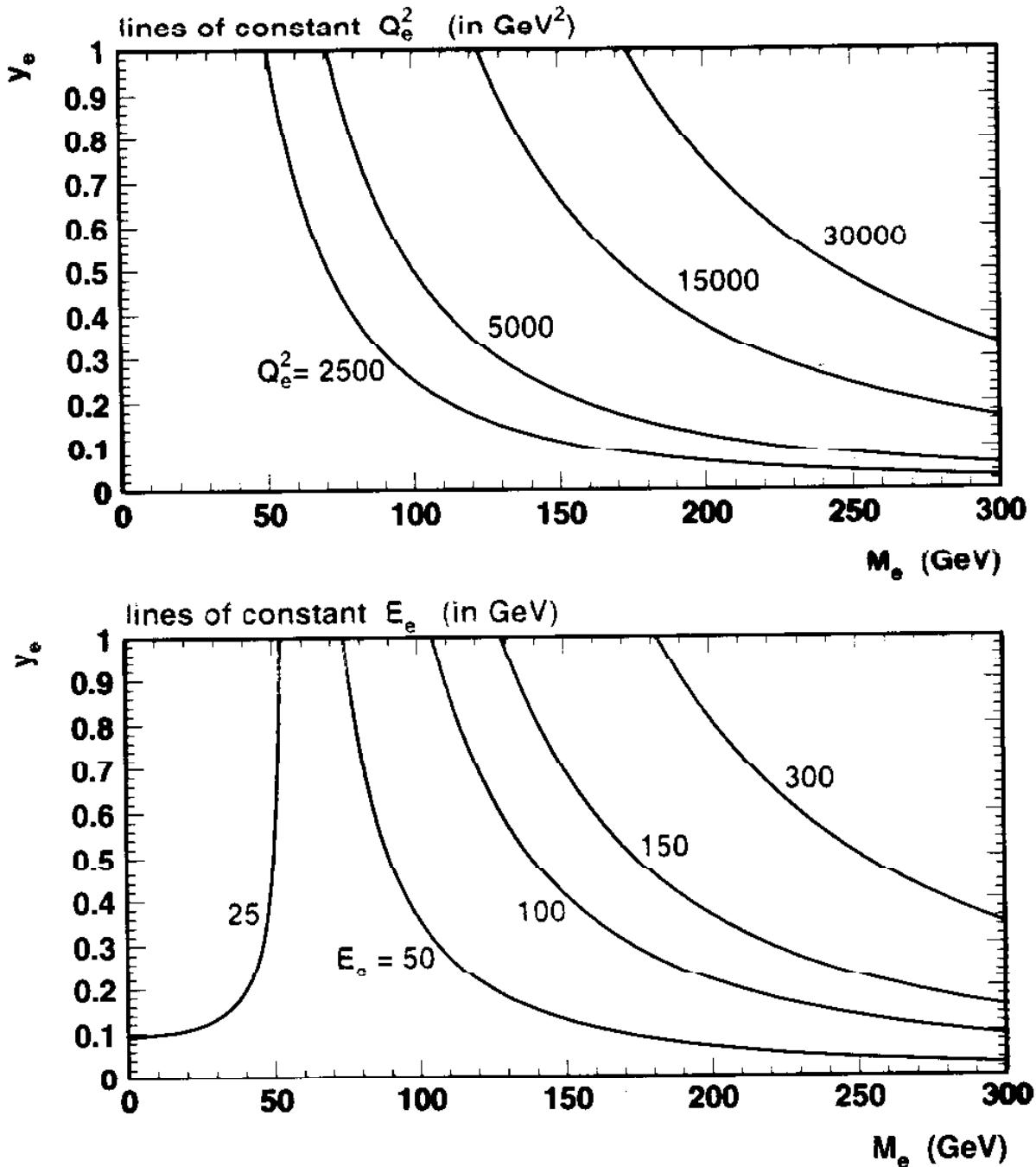
$$Q^2 = M^2 y$$

Probing the proton at very small distances:

$$Q^2 \leq 90000 \text{ GeV}^2$$

$$\sim 10^{-16} \text{ cm}$$

Kinematic of Deep Inelastic Scattering



Reconstruction of Kinematics

Observables: $E_e, \Theta_e, E_h, \Theta_h \rightarrow M, y, Q^2$

over constrained kinematics
due to momentum conservation

Electron method: E_e, Θ_e for NC results

$$\frac{\delta M_e}{M_e} \propto 1/y_e$$

Hadron method: E_h, Θ_h for CC results

$$\frac{\delta M_h}{M_h} \propto \frac{1}{1-y_h} \text{ for } y_h \sim 1$$

$$\frac{\delta Q^2_h}{Q^2_h} \propto \frac{1}{1-y_h} \text{ for } y_h \sim 1$$

Double angle method: Θ_e, Θ_h for systematics

~ independent of energy measurement

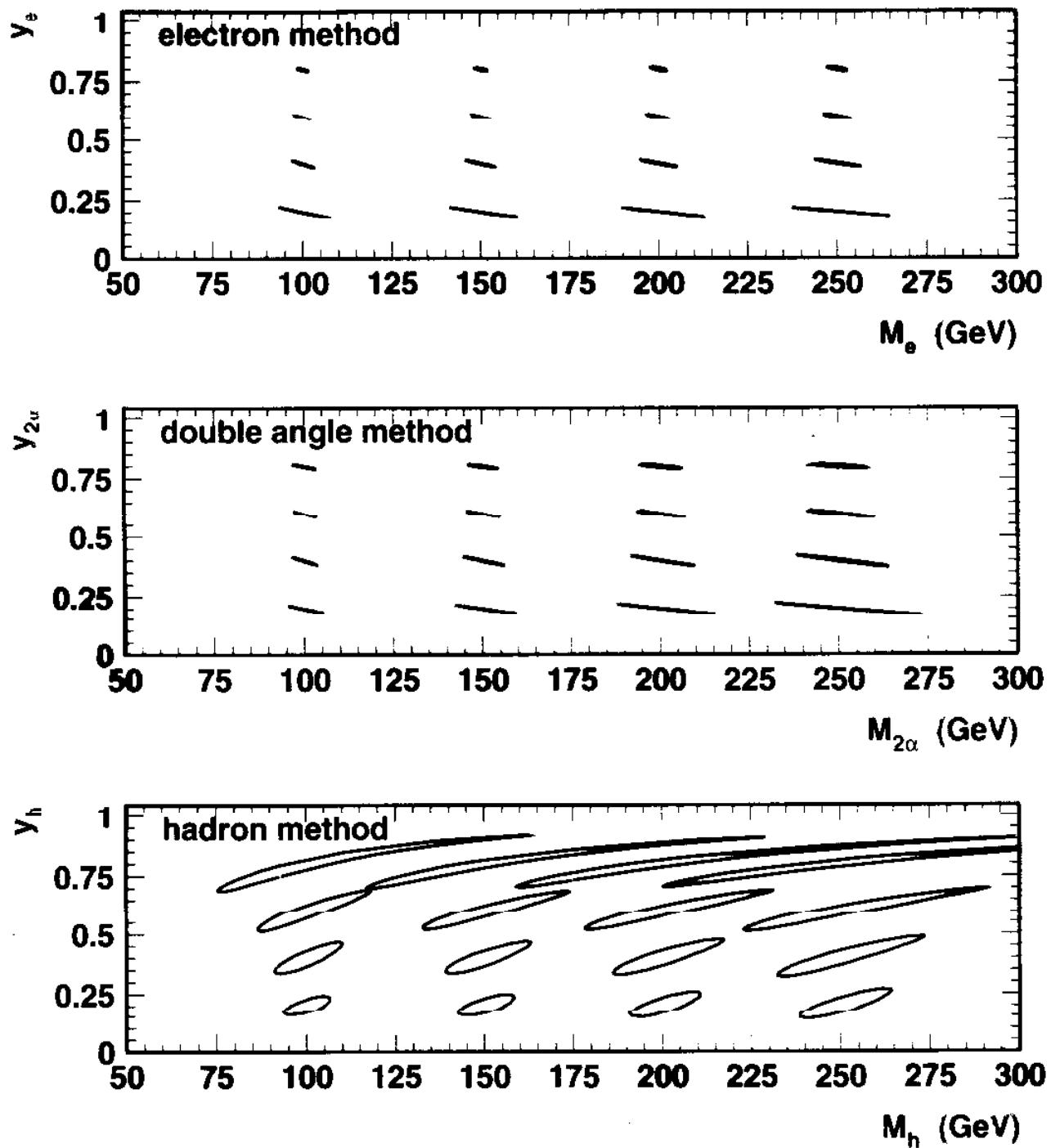
...but sensitive to initial state QED radiation

Sigma method: $E_e, \Theta_e, \sum_h E_h = P_{z,h}$ for systematics

...stable against initial state QED radiation

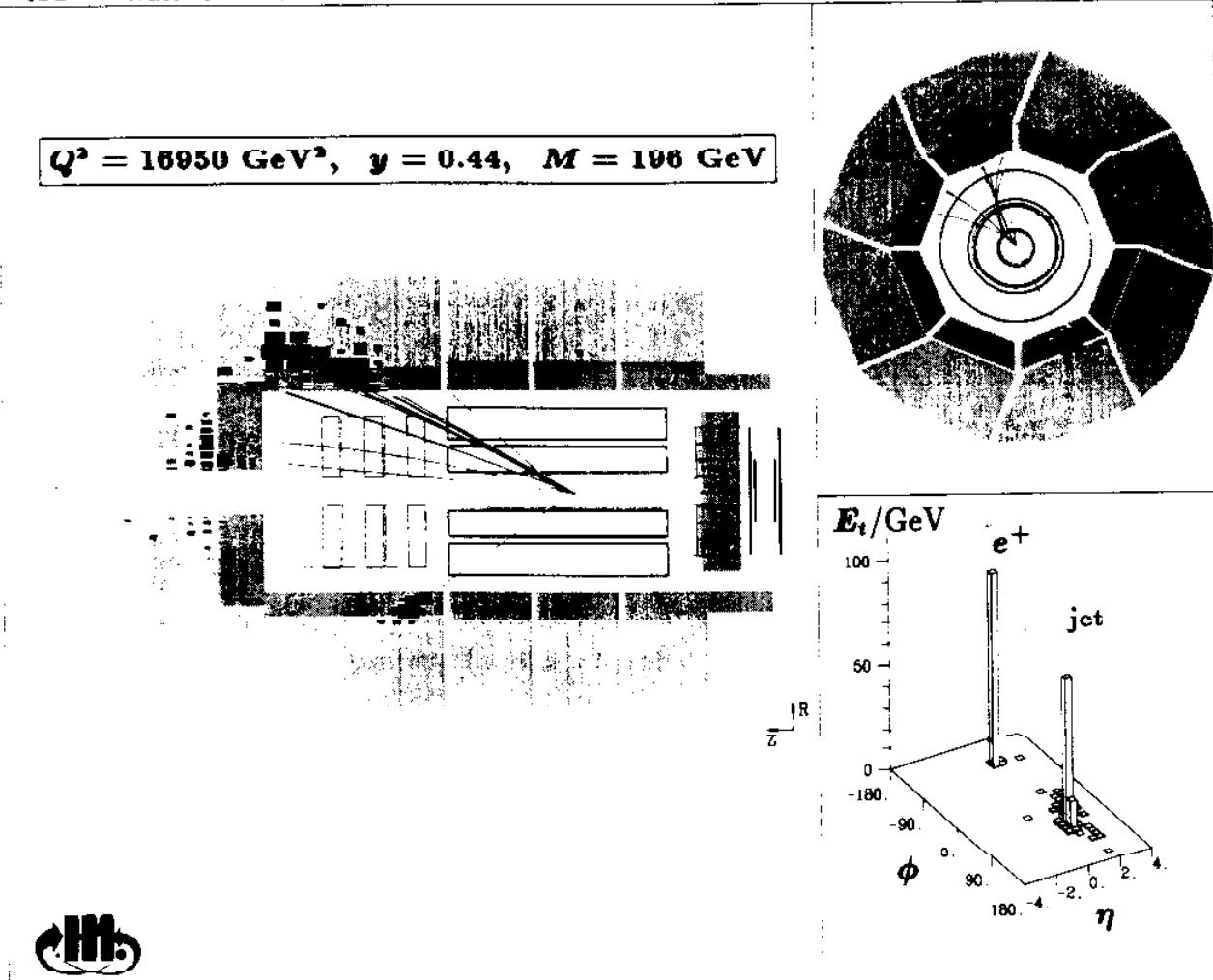
more sensitive at low y

Measurement errors for Mass and y



H1 Run 85528 Event 71329

Date 28/08/1994



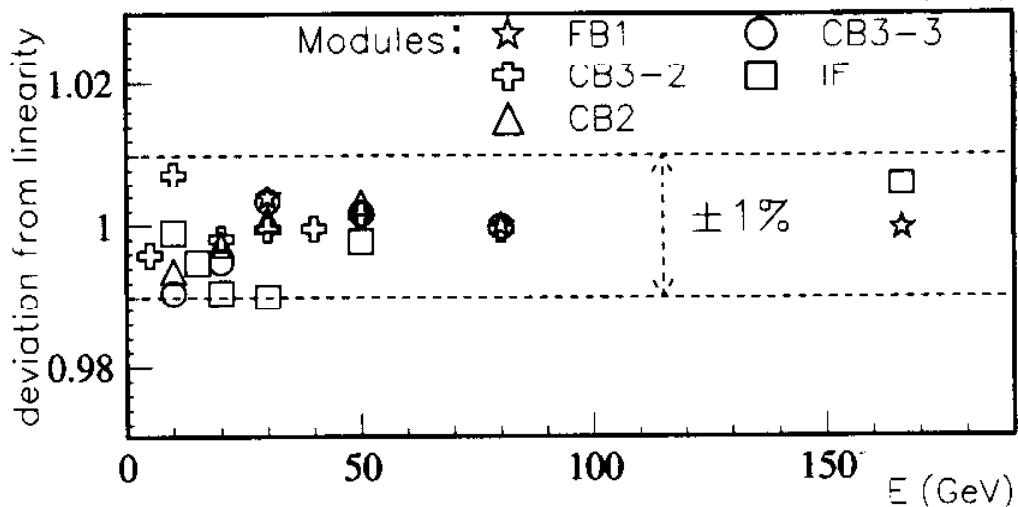
LAr Calorimetry

- Very fine granularity
(≈ 44000 cells)
 - Optimal for e identification
 - Hadronic energy compensation by off-line weighting
- $\Delta\theta_e \sim 2\text{mrad}$ for $10^\circ < \theta_e < 30^\circ$
 $\Delta\theta_e \leq 5\text{mrad}$ for $30^\circ < \theta_e < 145^\circ$
- $\sigma(E)/E \simeq 12\%/\sqrt{E/\text{GeV}} \oplus 1\%$
 $\sigma(E)/E \simeq 50\%/\sqrt{E/\text{GeV}} \oplus 2\%$

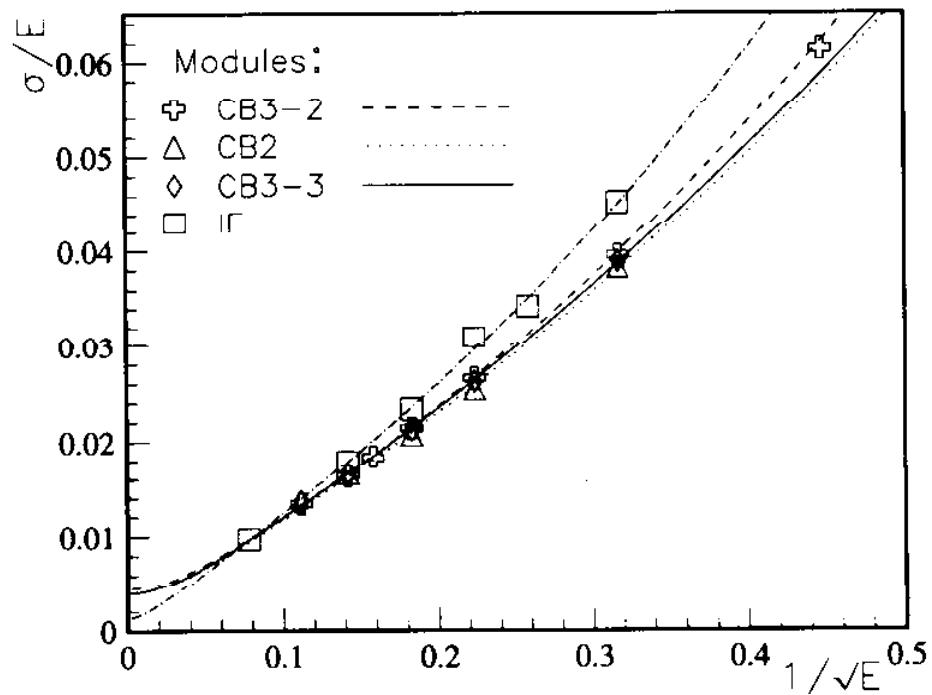
TEST BEAMS: E_e up to 166 GeV E_π up to 205 GeV

Electron Test Beam Results

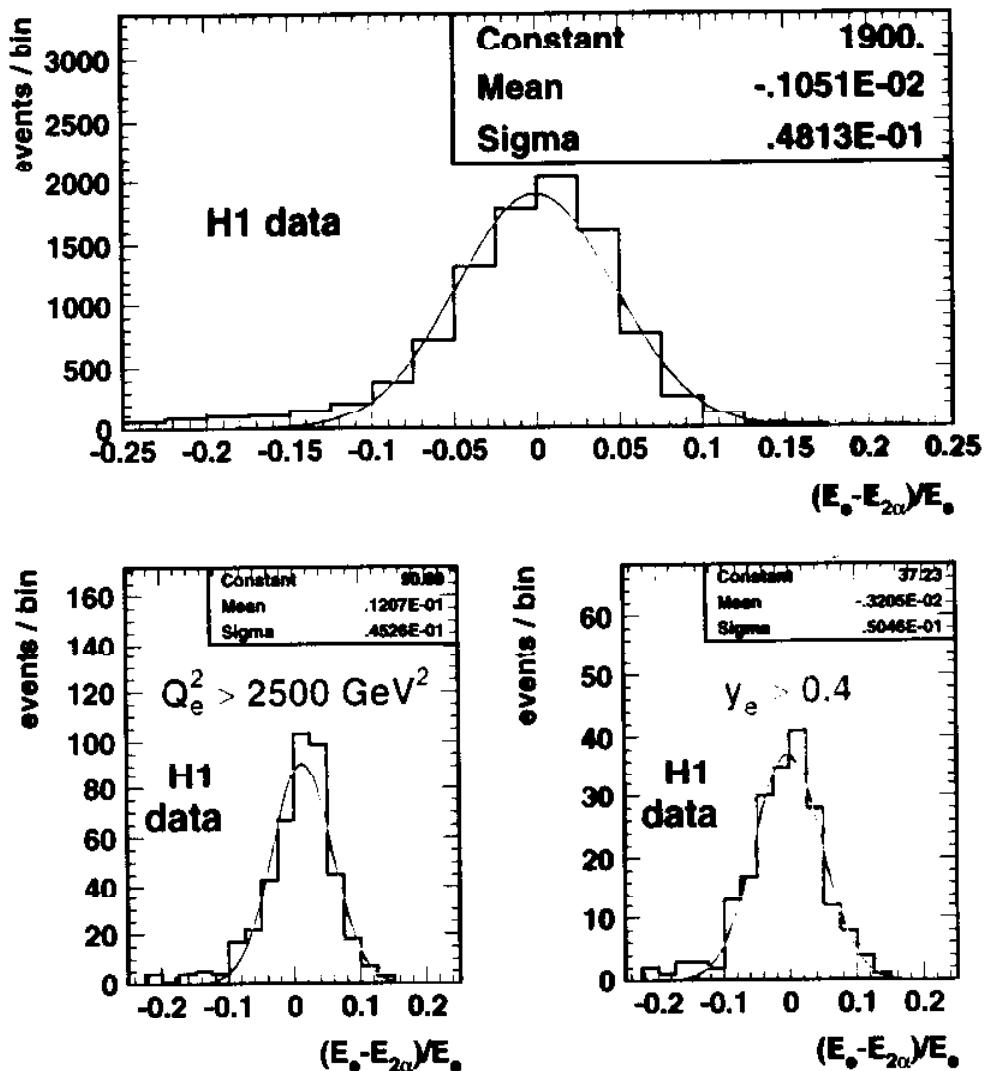
Linearity: $\pm 1\%$ up to $E_e = 166$ GeV



Resolution: $\sigma_e/E_e \simeq 12\%/\sqrt{E_e(\text{GeV})}$



Electromagnetic calibration



Uncertainty on e.m. energy scale 3%

Uncertainty on had. energy scale 4%

Selection of $e^+p \rightarrow e^+X$ Events

e^+p data from 1994-1996:

$$\int \mathcal{L} = 14.19 \pm 0.32 \text{ pb}^{-1}$$

Background Rejection

- vertex within nominal interaction region
- within ep interaction time
(tracking chamber $\pm 1.6\text{ns}/\text{event}$)
- filters against cosmic and halo muons
(μ -system, calorimeter and tracking)

Neutral Current Selection

- electron identification:
 - shower shape test in calorimeter
 - isolation in $\eta - \phi$ cone ($R < 0.25$)
 - track matching the calorimeter cluster

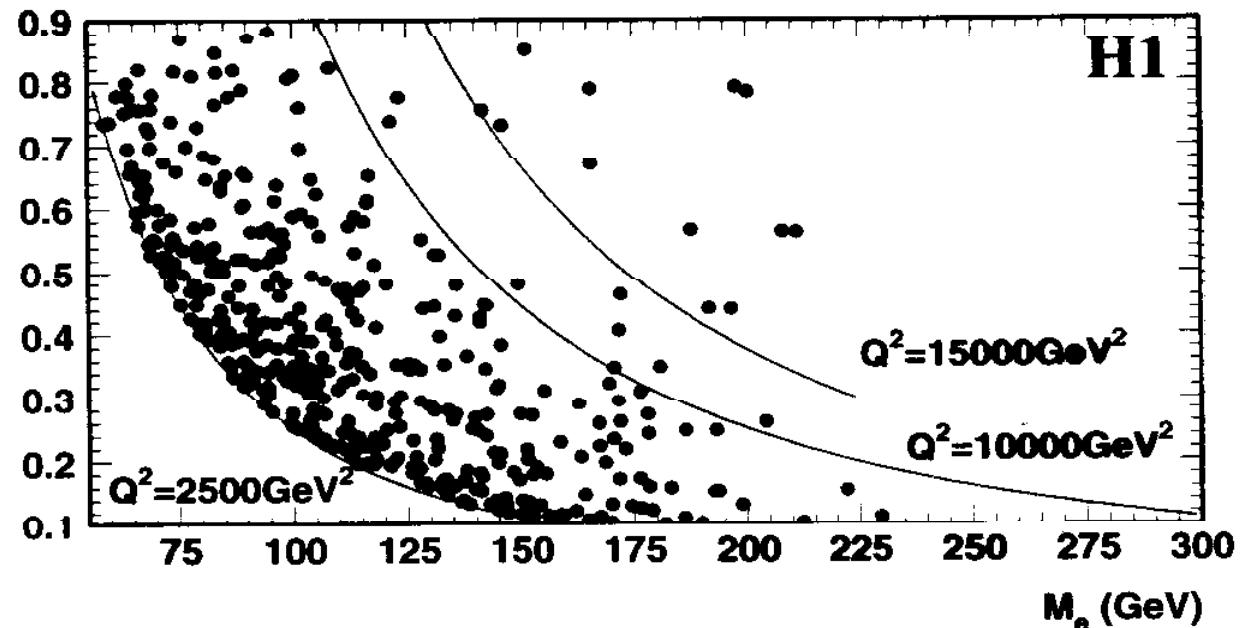
- $E_{T,\gamma} > 25 \text{ GeV}$
- $0.1 < y < 0.9$

$$|\Theta| > 10^\circ$$

$$Q^2 > 2500 \text{ GeV}^2$$

- momentum balance
 - transverse: $P_{T,miss}/\sqrt{E_T} < 3\sqrt{\text{GeV}}$
 - longitudinal: $43 < \sum E - P_z < 63 \text{ GeV}$
 $2E_e^o = 55 \text{ GeV}$ expected
cuts events with initial state radiation

$e^+ p \rightarrow e^+ X$ Events in the (M,y) Plane



Observed: 443 events

Expected: 427 ± 38 events

Selection efficiency: $(N_{exp}/N_{gen} \sim 80\%)$

Prediction of Standard DIS

Quark densities at large (x, Q^2)

- x -dependence from data at small Q^2

μ - nucleon scattering: BCDMS, NMC, SLAC $x < 0.8$

ν - nucleon scattering: CCFR, CDHS $x < 0.7$

incl. lepton, direct γ : $p\bar{p}$ exp. $x < 0.5$

ep scattering: H1, ZEUS $x < 0.3$

- Parametrisations of parton densities

MRS, CTEQ, GRV: H1 uses MRS H

$\pm 5\%$

- QCD evolution to large Q^2

using next-to-leading DGLAP

- $F_L = 0$

γ/Z^0 exchange

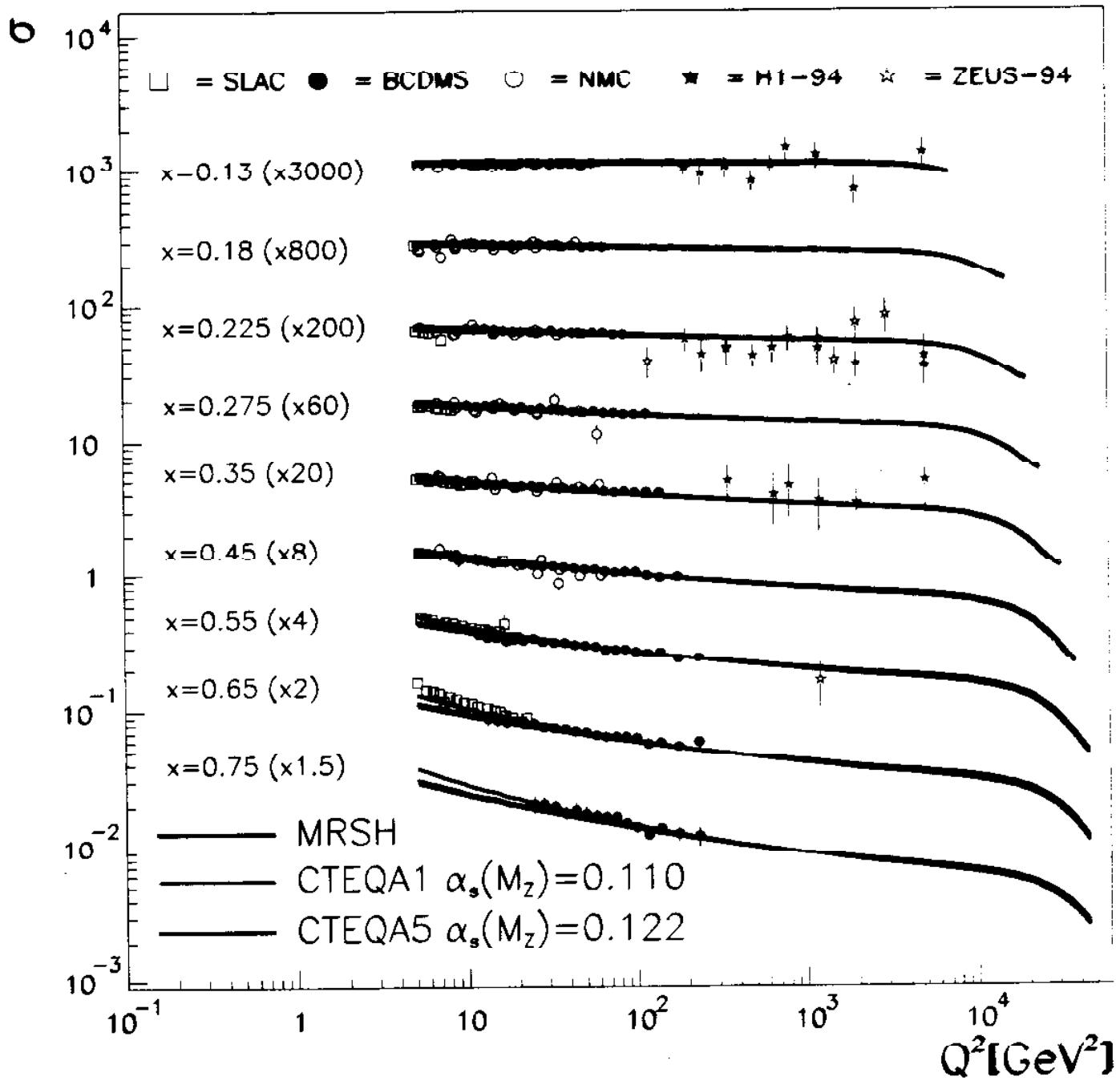
- electro-weak parameters: \rightarrow LEP

- QED radiative corrections

$\pm 2\%$

Systematic uncertainty: 7%

Predicted DIS Cross-section

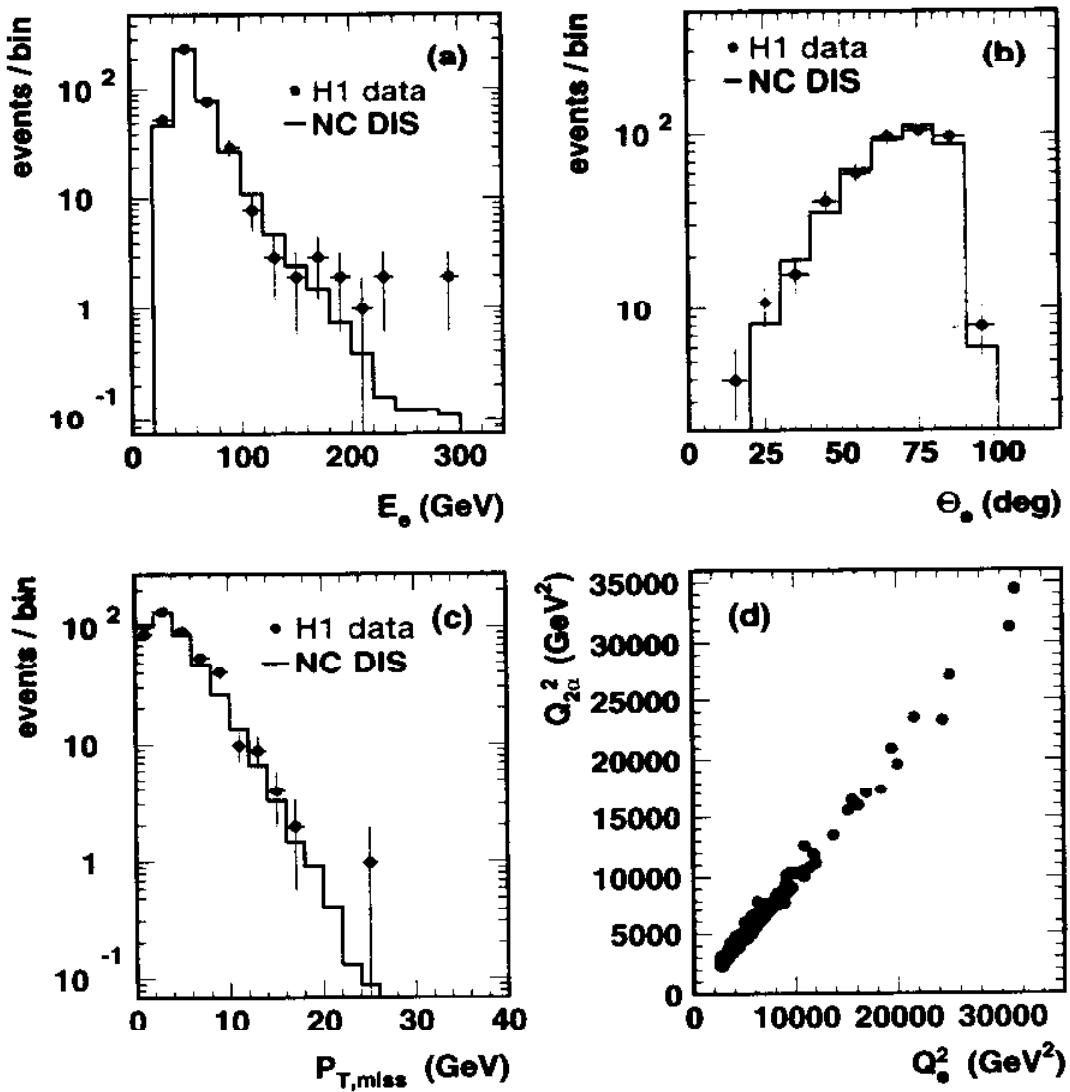


Background from other Processes

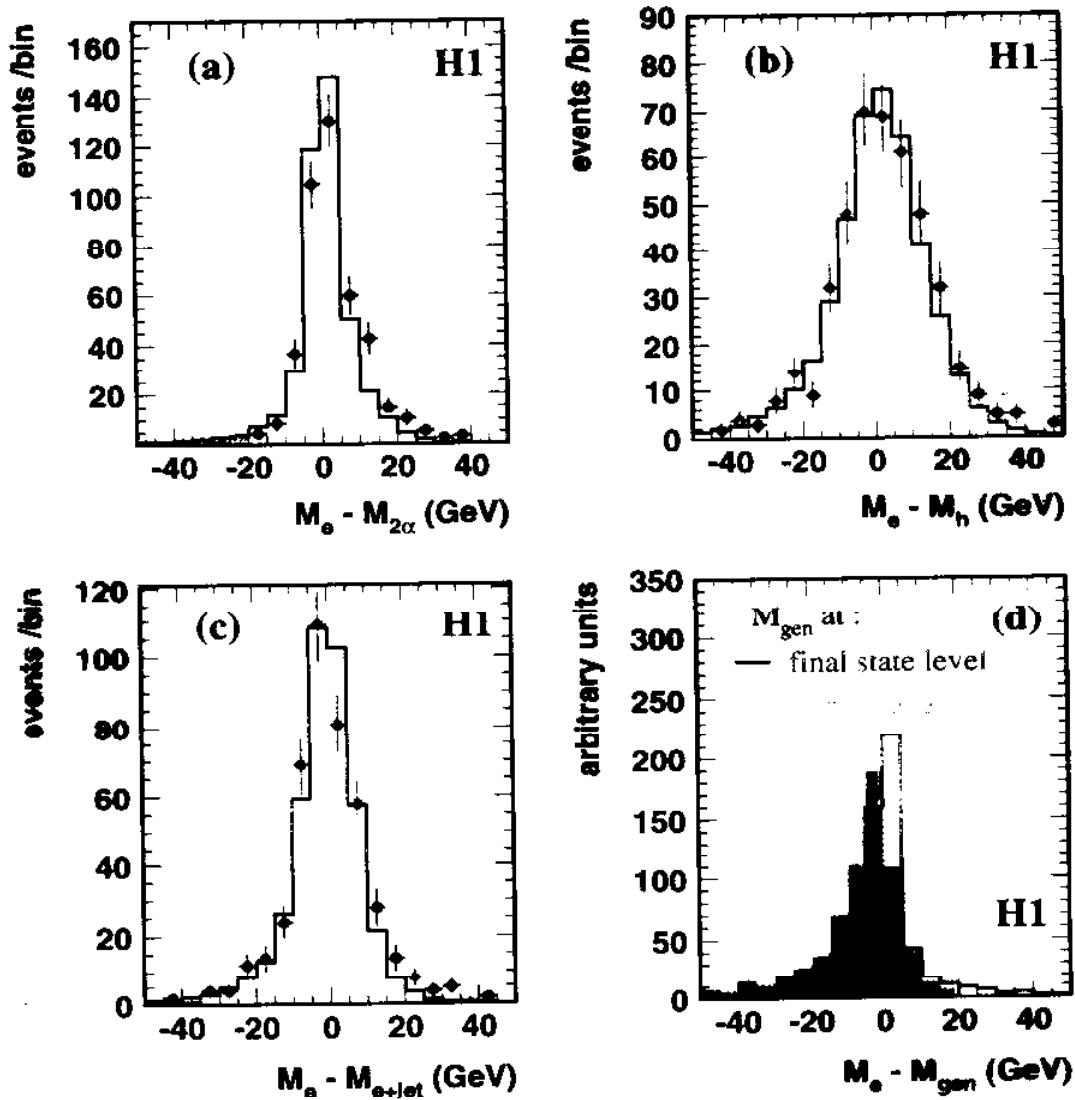
Partonic Process (example)	Generator Model [refs.]	Simulated Luminosity (pb^{-1})	Upper Limits (95% CL) on Events per $14.19\ pb^{-1}$
Single W and Z Boson Production			
$e + q \rightarrow W + e + X$			
$\hookrightarrow e + \nu$	H1EPVEC	8600	0.005
$\hookrightarrow \text{jet} + \text{jet}$		1400	0.16
$e + q \rightarrow Z + e + X$			
$\hookrightarrow e^+ + e^-$	H1EPVEC	42000	0.003
$\hookrightarrow \tau^+ + \tau^-$		59000	0.001
$\hookrightarrow \text{jet} + \text{jet}$		3600	0.18
High P_T jets photoproduction (direct and resolved)			
$\gamma + q \rightarrow q + g, \quad \gamma + g \rightarrow q + \bar{q}'$			
(hard jet)	PYTHIA	500	0.38
(hard fragmentation)		500	0.31
Heavy Flavour Production (direct and resolved)			
$\gamma + g \rightarrow c + \bar{c}$	PYTHIA	600	0.07
$\gamma + g \rightarrow b + \bar{b}$		600	0.07
Prompt Photon Production (direct and resolved)			
$\gamma + q \rightarrow q + \gamma$	PYTHIA	500	0.09
Two-photon processes			
$\gamma + \gamma \rightarrow e^+ + e^-$	LPAIR	1500	0.04
$\gamma + \gamma \rightarrow q + \bar{q}$		17000	0.002

Contamination = $\sim 0.5\%$ / full NC sample
 less than 0.1 event / 5% / at $Q^2 > 10000\ \text{GeV}^2$

Basic Quantities of $e^+ p \rightarrow e^+ X$ Events

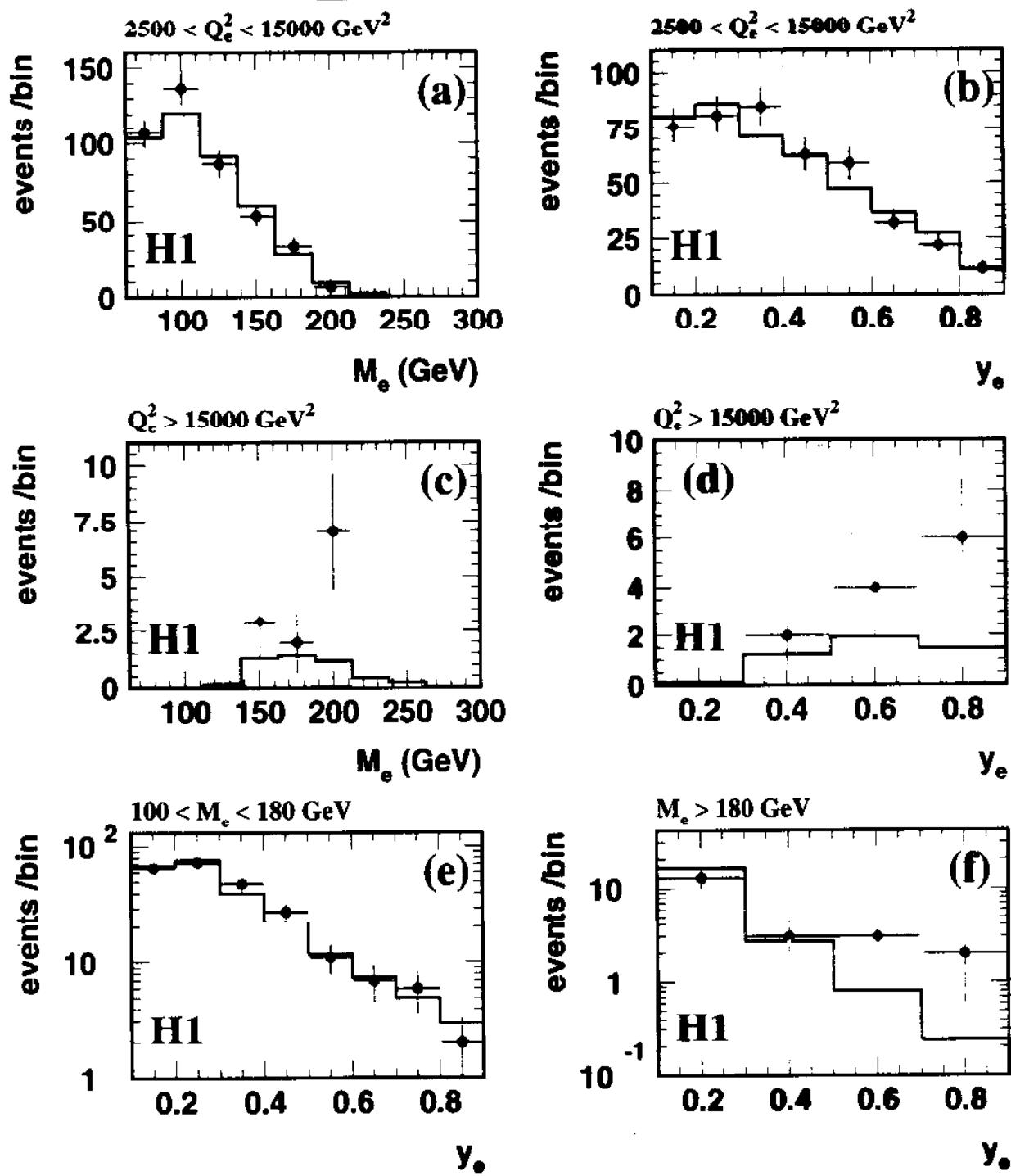


Mass Reconstruction



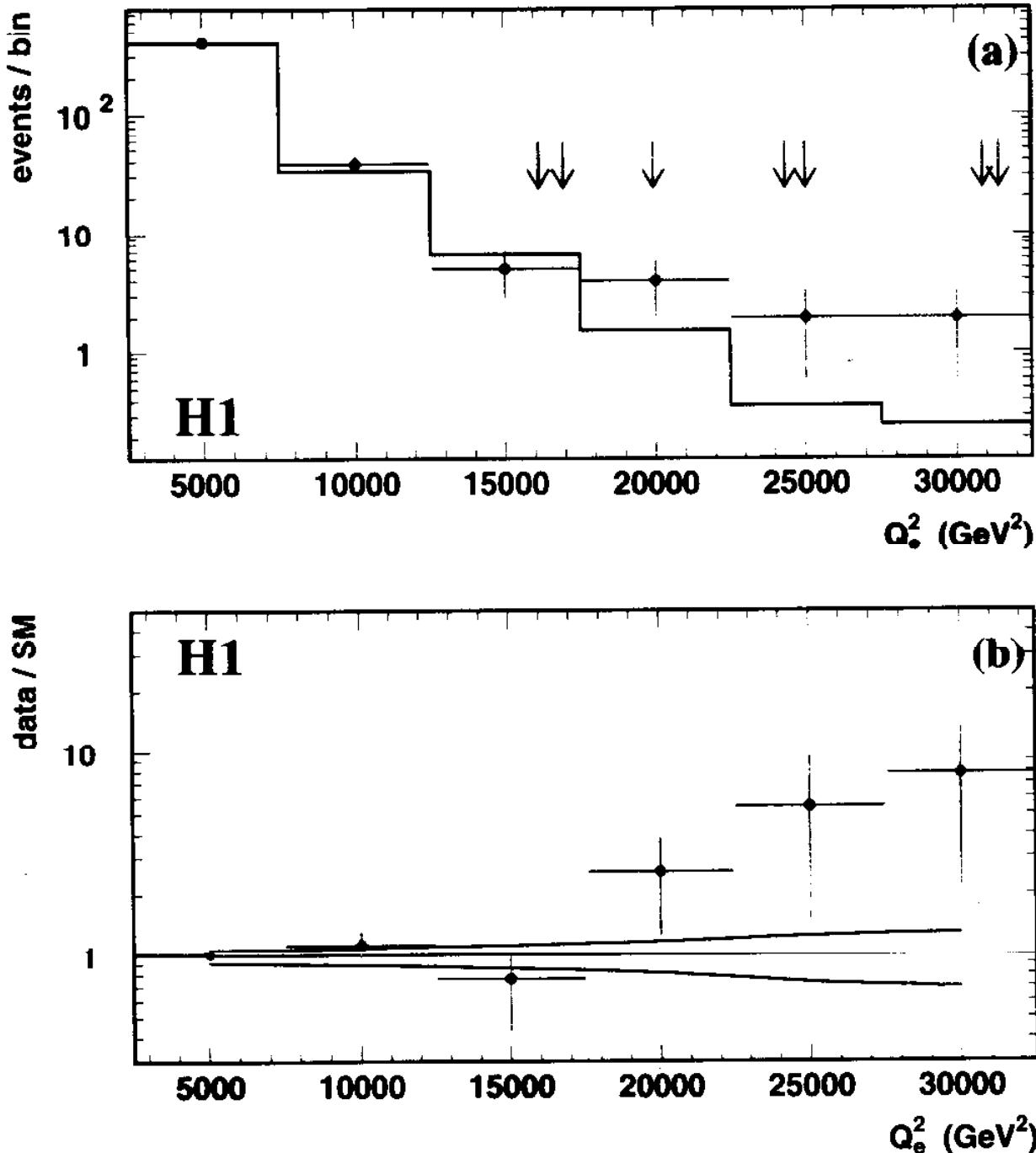
Consistency between various reconstruction methods

Kinematic Quantities



- data exceeds NC DIS expectation at high Q^2 especially at large M_e
- at high $M_e \Rightarrow$ difference apparent at large y_e .

Q^2 Distribution



Errors dominated by uncertainty on e.m. energy scale
 $\sim 8.5\%$ at low Q_e^2 $\sim 30\%$ at highest Q_e^2

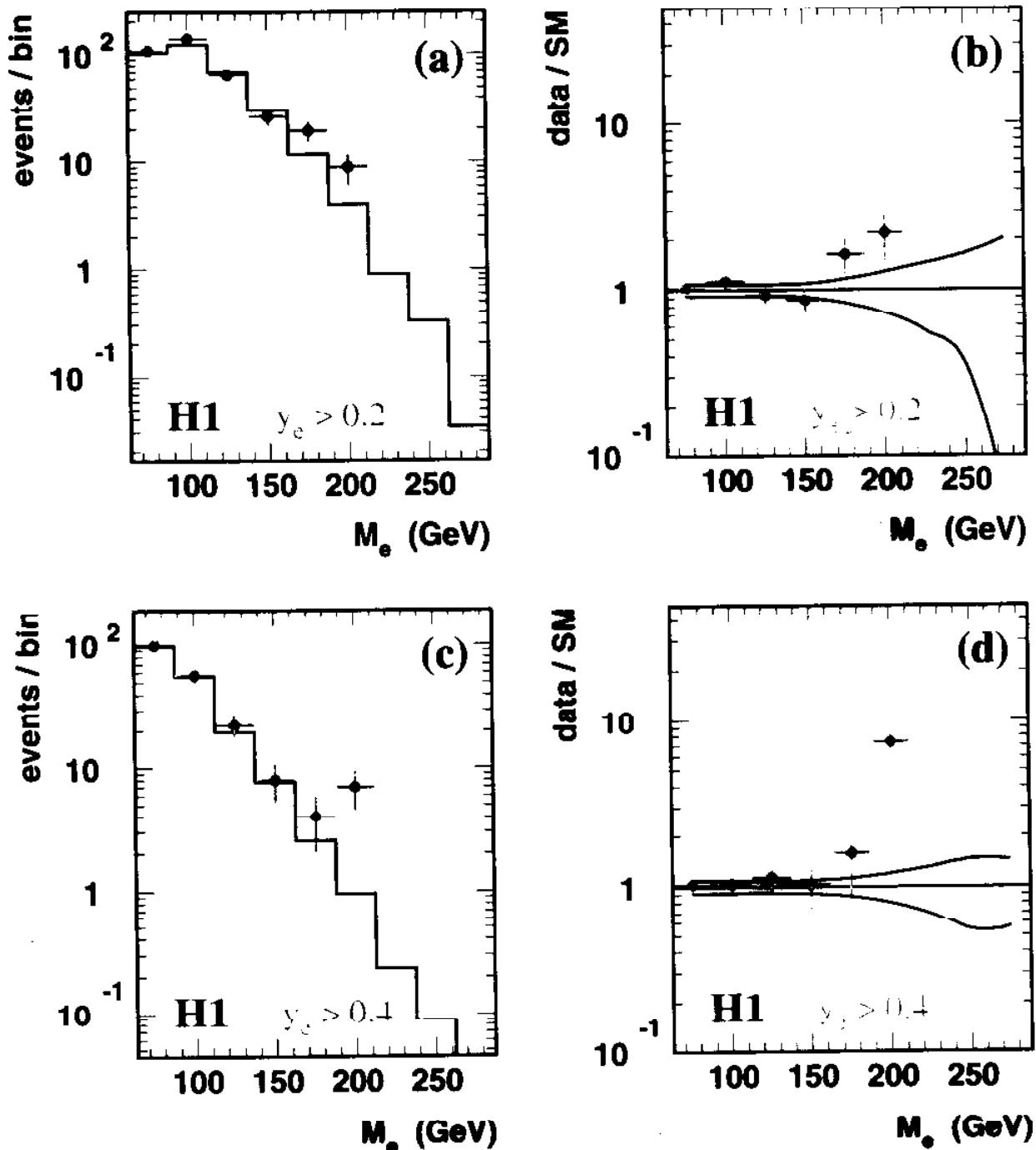
$$\mathcal{P}(N \geq N_{obs}) = \int_0^{+\infty} dx G(x; b, \delta b) \sum_{k=N_{obs}}^{\infty} p(k; x)$$

where:

- $p(k; x) = e^{-x} x^k / k!$ to observe k events for x expected events;
- $G(x; b, \delta b)$ = Gaussian of mean value b and width δb .

Q^2_{min} (GeV 2)	2500	5000	10000	15000	20000	30000
N_{obs}	443	122	20	12	5	2
N_{DIS}	426.7	116.2	18.3	4.71	1.32	0.23
$\mathcal{P}(N \geq N_{obs})$	± 38.4	± 11.6	± 2.4	± 0.76	± 0.27	± 0.05
	0.35	0.35	0.39	6×10^{-3}	1.4×10^{-2}	2.3×10^{-2}

Mass dependence



- Excess seen at highest mass

- More visible at large y_e

$e^+ p \rightarrow eX$ events with $M > 180$ GeV, $y_e > 0.4$

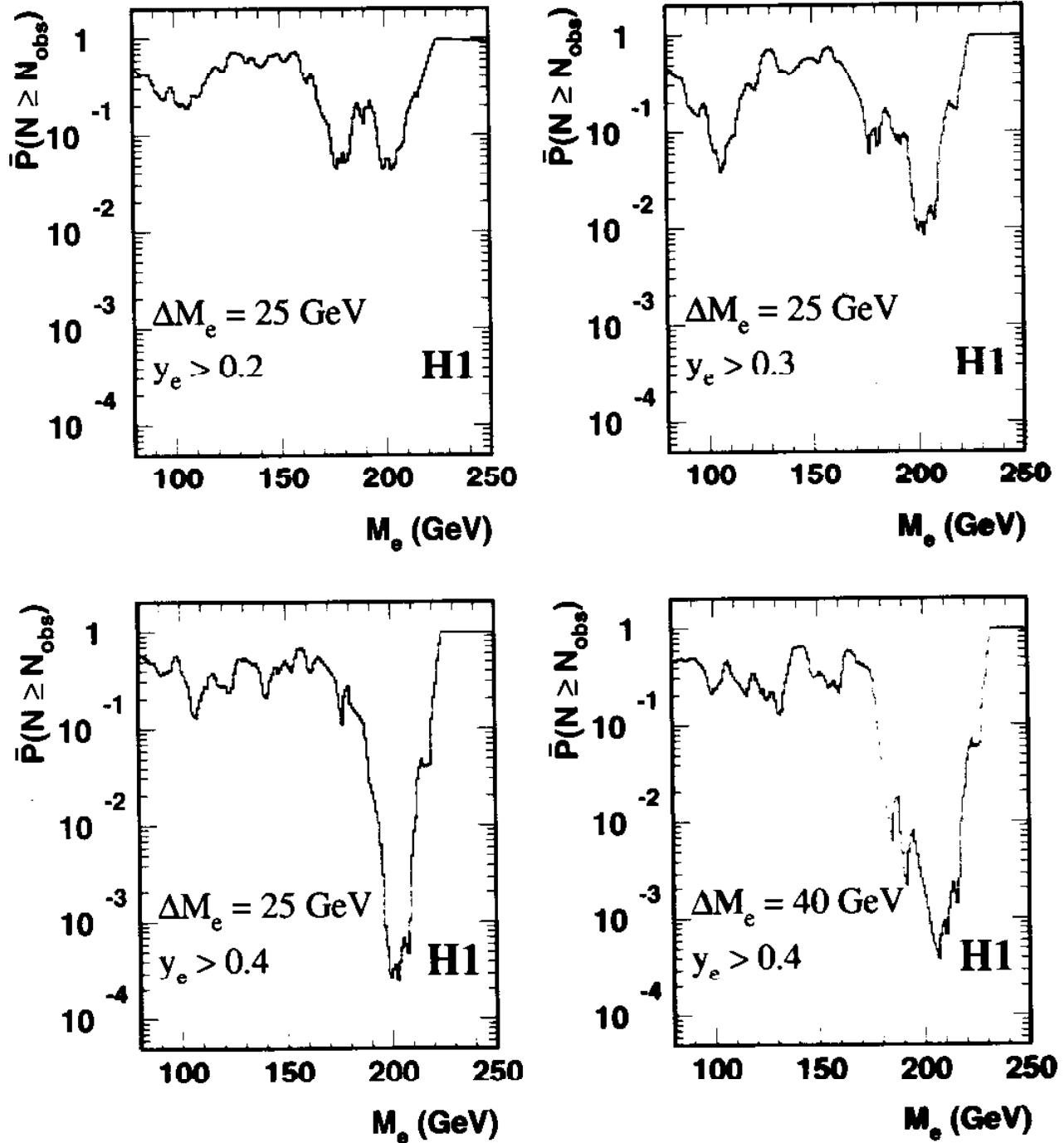
event	M_e (GeV)	M_Σ (GeV)	y_e	y_Σ	Q_e^2 (GeV 2)	Q_Σ^2 (GeV 2)
1	196 ± 5	196	0.439 $\pm .014$	0.443	16950 ± 360	17100
2	208 ± 4	209	0.563 $\pm .012$	0.592	24350 ± 430	25930
3	188 ± 12	188	0.566 $\pm .032$	0.561	19950 ± 1400	19760
4	198 ± 2	196	0.790 $\pm .008$	0.786	30870 ± 530	30230
5	211 ± 4	210	0.562 $\pm .012$	0.525	25030 ± 440	23120
6	192 ± 6	190	0.440 $\pm .016$	0.501	16130 ± 400	18140
7	200 ± 7	202	0.783 $\pm .008$	0.786	31420 ± 540	31940

Consistency between reconstruction methods (also double angle/e+jet)

Mean value: $M_e = 200.8$ GeV ± 2.2 GeV

Systematic error: $dE_e/E_e = 3\% \rightarrow \delta M = \pm 5$ GeV

Probability in sliding Mass Window



expected ~ 0.3 events for $M_e > 220$ GeV

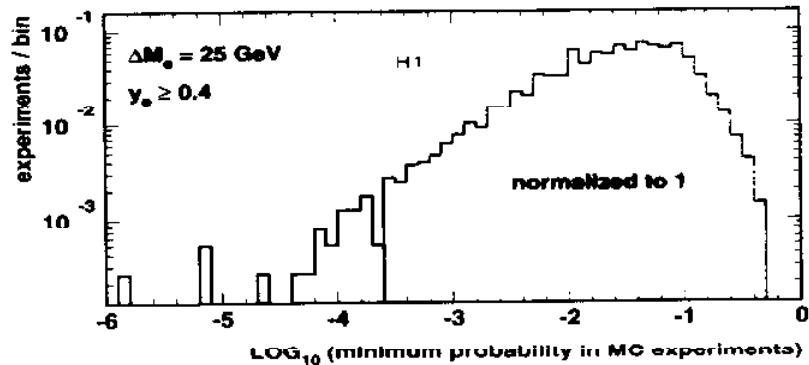
P=1 by construction

Dependence on the Window Size

ΔM_e (GeV)	20	25	30	40
N_{obs}	5	7	7	7
N_{DIS}	0.63 ± 0.13	0.95 ± 0.18	1.10 ± 0.19	1.57 ± 0.28
$\bar{\mathcal{P}}(N \geq N_{obs})$	5.0×10^{-4}	2.6×10^{-4}	2.5×10^{-4}	1.6×10^{-3}

\mathcal{P} to find a fluctuation as large as observed anywhere in the considered mass range:

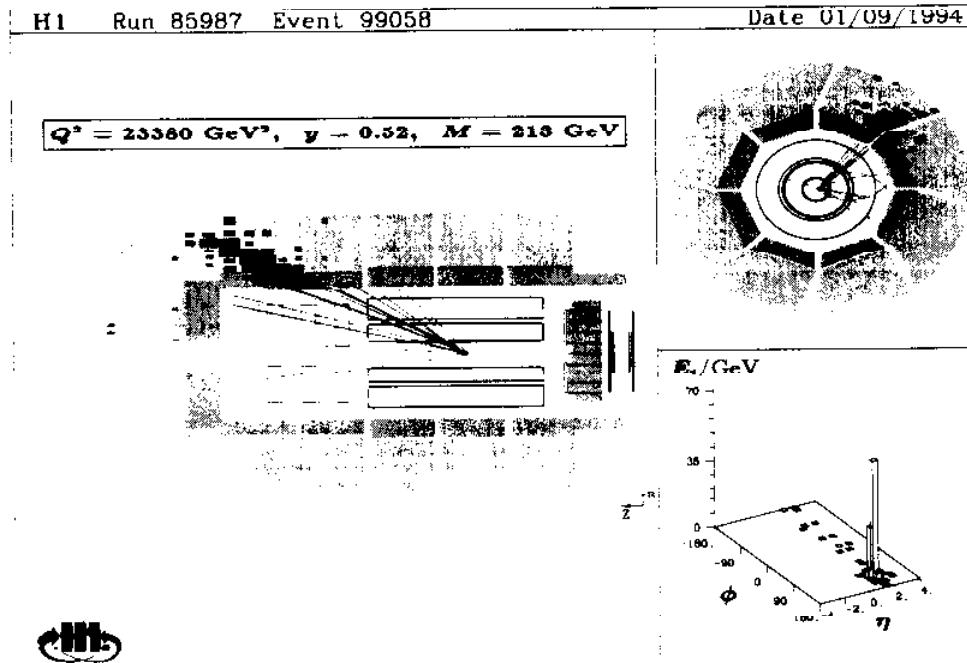
Lowest Probability in Monte Carlo Experiments



$$\overline{\mathcal{P}} = 0.01$$

$$e^+ p \rightarrow \bar{\nu} + \text{jet Event}$$

CC candidate ($p_t = 106$ GeV)



Event Selection

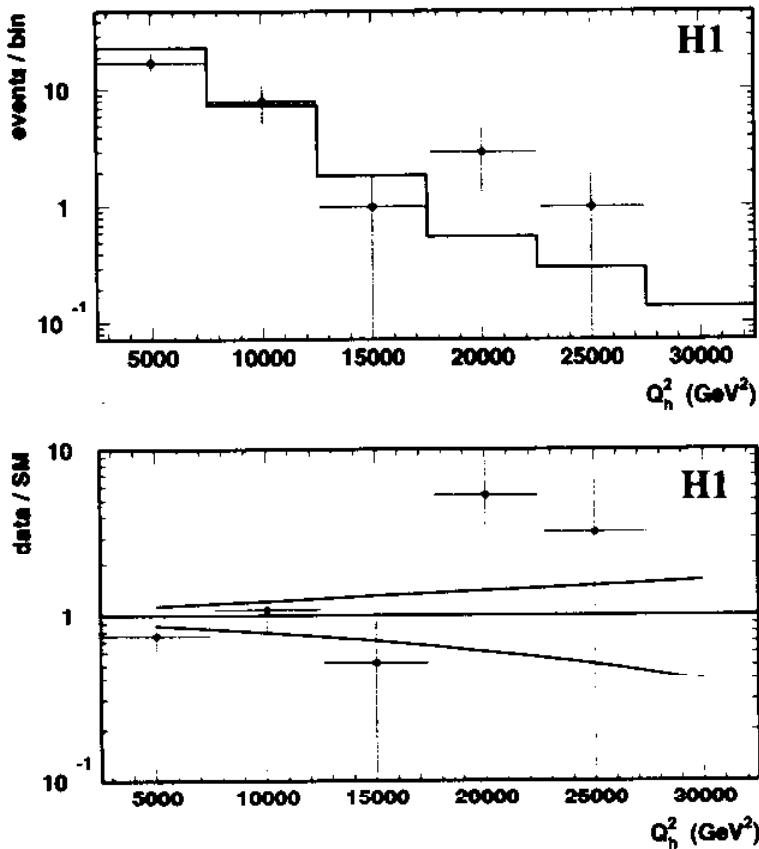
- $P_{T,h} > 50 \text{ GeV}$
- $(E_{T,h} - P_{T,h})/E_{T,h} < 0.5$

Transverse momentum: $P_{T,h}$ vectorial, $E_{T,h}$ scalar
for $y_h < 0.9$ and $P_{T,h} > 50 \text{ GeV}$

Observed: 31 events

Expected: 34.2 ± 5.8 events

Q^2 Distribution for $e^+p \rightarrow \bar{\nu} + \text{jet}$ Events



CC Event list at $Q^2 > 15000 \text{ GeV}^2$

	Run # / Event #	M_h	y_h	Q_h^2
1	85987/ 99058	213	.52	23380
2	153720/199055	187	.58	20170
3	163852/20613	157	.75	18650
4	169851/206239	192	.56	20800

Studied Uncertainties DIS

σ_{DIS} at large x and Q^2

- QCD Q^2 evolution works for $200 - 15000 \text{ GeV}^2$
- vary α_s in parton densities
 $0.110 < \alpha_s < 0.122$ 4%
- knowledge of higher order QED corrections 2%
- ignore data (BCDMS) at low Q^2 ($\sigma_{DIS} \rightarrow +20\%$)
- $F_i \neq 0$ reduced σ_{DIS}
- non standard QCD effects small

→ DIS is well constraint by data up to $Q^2 \approx 15000 \text{ GeV}$
no mechanism increasing σ_{DIS} found so far

Only explanation: statistical fluctuation

Summary

- For $Q^2 \leq 15000 \text{ GeV}^2$, the Q^2 , M and y distributions are well reproduced by DIS expectations
- For $Q^2 > 15000 \text{ GeV}^2$ an excess of $e^+p \rightarrow eX$ events is seen:
 $N_{obs} = 12$ events for 4.71 ± 0.76 expected
 $P(N \geq N_{obs}) = 6 \times 10^{-3}$
- The excess in the M and y plane is most prominent for large y at $M = 200 \pm 12.5 \text{ GeV}$.
 ≈ 7 events for 0.95 ± 0.18 expected.
Probability for comparable or larger excess anywhere in the mass region considered = $\mathcal{O}(1\%)$
- The excess cannot be accounted for by:
 - detector effects
 - parton densities compatible with existing data
 - variation of α_s
 - higher order corrections

Explanation: either a statistical fluctuation or new physics

New data taking already started $\sim 2 \text{ pb}^{-1}$ already on tape !
Aim to double statistics until end of 1997